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Improved feeding and forages at a crossroads: Farming systems approaches for sustainable livestock development in East Africa

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Abstract

Dairy development provides substantial potential economic opportunities for smallholder farmers in East Africa, but productivity is constrained by the scarcity of quantity and quality feed. Ruminant livestock production is also associated with negative environmental impacts, including greenhouse gas (GHG) emissions, air pollution, high water consumption, land-use change, and loss of biodiversity. Improved livestock feeding and forages have been highlighted as key entry point to sustainable intensification, increasing food security, and decreasing environmental trade-offs including GHG emission intensities. In this perspective article, we argue that farming systems approaches are essential to understand the multiple roles and impacts of forages in smallholder livelihoods. First, we outline the unique position of forages in crop-livestock systems and systemic obstacles to adoption that call for multidisciplinary thinking. Second, we discuss the importance of matching forage technologies with agroecological and socioeconomic contexts and niches, and systems agronomy that is required. Third, we demonstrate the usefulness of farming systems modeling to estimate multidimensional impacts of forages and for reducing agro-environmental trade-offs. We conclude that improved forages in East Africa are at a crossroads: if adopted by farmers at scale, they can be a cornerstone of pathways toward sustainable livestock systems in East Africa.

Keywords

Sub-Saharan Africa, farming systems, improved forages, livestock feeding, bio-economic modeling, sustainable intensification, technology adoption, systems agronomy, forage grass, dual-purpose forage legume

Introduction

Livestock is a resource of significant benefit to society in the form of food, income, nutrients, employment, insurance, traction, and clothing (Herrero et al., 2013). By 2050, the total demand for meat, milk, and eggs is projected to almost double mostly in the developing world due to population growth, urbanization, income increase, and change in dietary preferences—the "livestock revolution" (Alexandratos and Bruinsma, 2012). In East Africa, the majority of the mixed crop-livestock systems are rain-fed and located in the tropical highlands and subhumid and humid zones (Figure 1). Upgrading and intensification of smallholder dairy development is seen as a viable poverty alleviation strategy. It can provide opportunities for daily income throughout the year, in contrary to crop income that is bound to harvest seasons. Milk has even been coined "white gold" for its potential of income generation (Makoni et al., 2013).

However, livestock is also associated with a number of negative environmental impacts, including greenhouse gas

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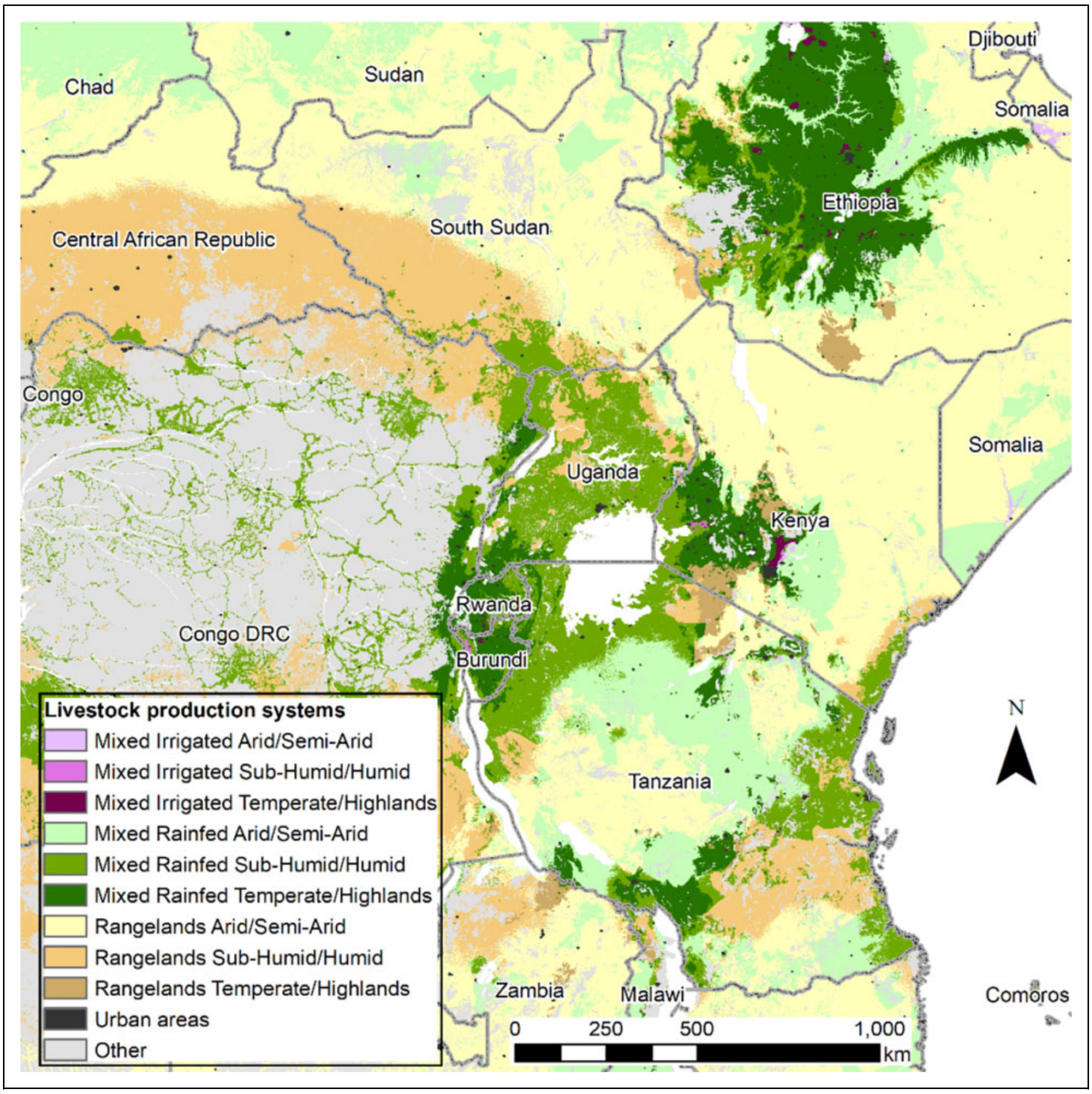

Figure 1. Livestock production systems across East Africa (Robinson et al., 2014).

(GHG) emissions, air pollution, high water consumption, loss of biodiversity, and land degradation (Herrero et al., 2015). Therefore, sustainable intensification of livestock production systems has become a global research priority. In Sub-Saharan Africa (SSA), the primary aim is to improve smallholder livelihoods, while mitigating negative environmental impacts is a co-benefit through efficiency gains (Campbell et al., 2014). Improved livestock feeding and forages have previously been highlighted as a triple-win strategy toward achieving climate-smart agriculture, increasing food security and resilience, and decreasing GHG emission intensities (Bryan et al., 2013; Peters et al., 2013; Thornton and Herrero, 2010). Climate change mitigation by improved forages can be achieved through (i) increased carbon accumulation particularly in deeper soil layers through conversion from cropland to perennial, sown forages; (ii) reduced methane emissions from enteric fermentation through higher nutritional value and digestibility of feed that reduces emissions per unit milk or meat produced; (iii) lower nitrous oxide emissions through high biological nitrification inhibition capacities of, for example, some *Brachiaria* spp.; and (iv) increase of aboveground biomass through integration of fodder trees in agroforestry or silvo-pastoral systems (Peters et al., 2013).

In this perspective article, we argue that multidisciplinary farming systems approaches are essential to understand the multiple roles and impacts of forages in smallholder livelihoods. Systems approaches are needed that strive to overcome previous boundaries between disciplines (interdisciplinary) and between research and practice (transdisciplinary) (Hieronymi, 2013). First, we outline the unique position of forages in crop-livestock systems and systemic obstacles to adoption that call for multidisciplinary thinking. Second, we discuss the importance of matching forage technologies with agroecological and socioeconomic contexts and niches, and systems agronomy that is required. Third, we demonstrate the usefulness of farming systems modeling to estimate multidimensional impacts of forages and for reducing agro-environmental trade-offs.

Systems thinking to address constraints to forage adoption

Various studies from SSA have reported an inadequate supply of quality feed. In the East African subhumid highlands, feed shortage is pronounced especially in the dry season(s) or during prolonged dry spells (Lukuyu et al., 2009; Mutimura et al., 2015). In seven sites across West and East Africa, livestock milk yield gaps ranged from 45% in Lushoto, Tanzania, 55% in Nyando, and 40% in Wote, both in Kenya (Henderson et al., 2016).

Improved livestock feeding and forages can play an important role in alleviating such constraints in quantity and quality feed. Tropical forages include a wide variety of sown or planted grasses, annual and perennial herbaceous or dual-purpose legumes, and leguminous fodder shrubs and trees that are integrated into different agricultural systems to increase livestock productivity. Due to their diverse properties, they can play various roles and fulfill different objectives in crop-livestock systems (Rao et al., 2015; Rudel et al., 2015). Although botanical names have recently changed (Cook and Schultze-Kraft, 2015), we are referring throughout this article to original names as used in the publications cited. Grasses have been more popular than legumes among farmers due to lower maintenance requirements for planting and weeding, less pest and disease pressure, their perennial nature, and soil protection properties. Grasses are also regarded as more resilient and universally adapted than legumes (Peters and Lascano, 2003). Napier grass (*Pennisetum purpureum*) is a C4 grass native to SSA and widely used in cut-and-carry systems in East Africa due to its high herbage yields per unit area and relative tolerance to intermittent drought. However, it requires high soil fertility and is subject to disease pressure including stunt and smut diseases (Negawo et al., 2017). There are other well-documented forage technologies: leguminous fodder shrubs/trees including *Calliandra calothyrsus*, *Sesbania sesban*, and *Leucaena trichandra* in East Africa (Place et al., 2009); and herbaceous legumes (*Stylosanthes guianensis*, *Stylosanthes hamata*, and *Mucuna pruriens*) and dual-purpose legumes such as cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*) in West Africa (Kristjanson et al., 2005). Increased forage availability (*P. purpureum* or *Brachiaria* hybrid cv. Mulato II, and *Desmodium uncinatum* cv. Silverleaf—silverleaf desmodium—or *Desmodium intortum* cv. Greenleaf—greenleaf desmodium) has been a welcomed byproduct of the well-documented push–pull system (Kassie et al., 2018).

However, farmers' adoption of tropical forage technologies remains below expectations (de Haan et al., 2006; Owen et al., 2012). Often-cited reasons include the lack of awareness and knowledge, low support and investment from national and local authorities, lack of available, accessible and affordable forage seed and planting material, and lack of market linkages for inputs and outputs (Ndah et al., 2017; Owen et al., 2012; Peters et al., 2003). Several deeper-lying, systemic reasons can be identified that are linked to forages' unique and pivotal position in crop-livestock systems:

Land availability and tenure is not conducive: In areas with high agroecological potential and population pressure, farmers need to weigh between various land uses and associated opportunity costs. Food crops will often be prioritized over forage crops to ensure food self-sufficiency of the household. Cash crops, such as dry season horticultural crops, are an attractive income-generating activity when markets are available (Makoni et al., 2013). In Kenya, milk and meat production could be increased by 51% and 71%, respectively, but 50–300% more cropland would have to be converted to forages (Bosire et al., 2016). In Rwanda, one of the most highly populated countries in SSA, allocating sufficient land to forage cultivation is a major challenge (Klapwijk et al., 2014a). Lack of land tenure has been shown to discourage forage cultivation, especially for perennial forages (Njarui et al., 2017).

Entire production system needs to change: It requires a substantive production system change and cultural shift to replace (parts of) free grazing with cut-and-carry feeding of cultivated forages. Farmers who are unfamiliar with the concept of investing labor for planting, management and harvesting, and capital for seeds and land in producing feed that was previously acquired "for free" are more reluctant to start growing forages. Such investment is mostly common for food crops but not for feed (Thomas and Sumberg, 1995). Moreover, improved feeding needs to go hand in hand with a range of other technological changes to achieve expected production response. A farmer would have to improve the animal breed, provide drinking water, ensure veterinary services, and improve animal husbandry in order to reap benefits of higher milk production from feed improvements (Ndah et al., 2017). The adoption of several technologies at the same time is a challenge to smallholder farmers lacking investment capacity and access to knowledge.

Production intensification might not be primary objective: Most fundamentally, an obstacle to adoption might be that a farmer's objective has not been well defined (Sumberg, 2002). In SSA, farmers often manage livestock according to the weighing of their functions. Production intensification may not be the main priority for farmers that primarily keep livestock for providing drought power, as assets and risk management strategy, or for cultural reasons (Thomas and Sumberg, 1995). Multifunctionality of livestock might provide incentives for keeping large livestock herds at low productivity levels, instead of reducing stocking rates and investing in increased productivity (Descheemaeker et al., 2016a).

Systems agronomy to match forages with agroecological and socioeconomic contexts

Systemic obstacles to forage adoption, most notably land requirements and production objectives, underline the necessity of matching forage technologies with

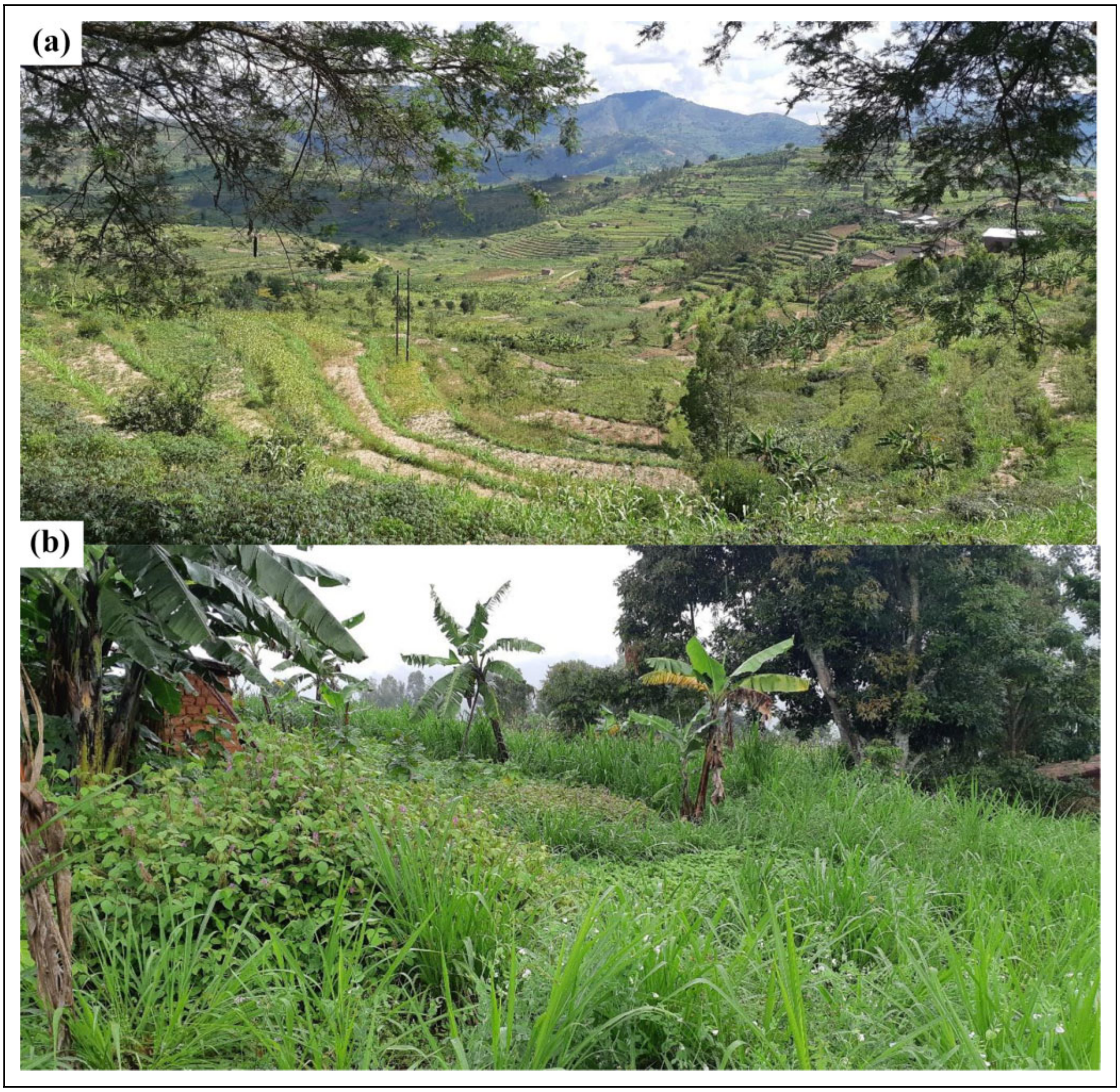

Figure 2. Napier grass grown on contours and terraces in Butare, Rwanda (a), and Napier intercropped with green peas in front, and *Desmodium distortum* with Napier grass in the background in Burera, Rwanda (b). Photo credits: Birthe Paul.

agroecological and socioeconomic contexts. Diverse forages can occupy different niches and fulfill different objectives in a given farming system. Skillful spatial and temporal integration into cropping systems, especially with food crops, is key in not compromising smallholders' food security and deliver multiple benefits (Ates et al., 2018; Rudel et al., 2015). The concept of socio-ecological niches refers to best-fit agricultural improvements that are adapted to the agroecological, sociocultural, economic, and institutional contexts (Descheemaeker et al., 2016b).

Few incipient studies have been conducted toward identifying cropping systems and socio-ecological niches for forages in SSA. In Rwanda, shade-tolerant grasses and legumes such as *Brachiaria* spp., greenleaf and silverleaf desmodium, and *M. pruriens* could be suitable for planting below public and private woodlots and bananas (Umunezero et al., 2016). Farm boundaries, roadside terraces, and contours have been popular niches for Napier grass and fodder shrubs/trees, especially in erosion-prone areas in the highlands of Rwanda (Figure 2(a)). Integration of forage grasses with food legumes on cropping land is another niche, such as Napier grass with green peas (*Pisum sativum*) (Figure 2(b)). The suitability of those niches depends on biophysical conditions and tolerance of forage species to, for example, soil acidity, slope, and shade, as well as socioeconomic factors such as distance to farms, policy regulations (Umunezero et al., 2016), and gender-related access to land. In highland areas in Madagascar, *Brachiaria* hybrid cv. Mulato and dual-purpose legumes *Lablab purpureus*, *Vicia villosa*, *Arachis pintoi*, and *S. guianensis* have been used as cover crop in conservation agriculture systems integrated with cassava, rice, and maize. A 30–60% residue retention rate was shown to be beneficial for soil fertility without compromising dairy cow feeding (Maass et al., 2015; Naudin et al.,2012). On-farm participatory research from DR Congo has demonstrated that 43% of farmers decided to intercrop forages with food crops such as maize or cassava, especially legumes such as *S. guianensis*, *Canavalia brasiliensis*, and silverleaf desmodium. The choice of forage species and their integration

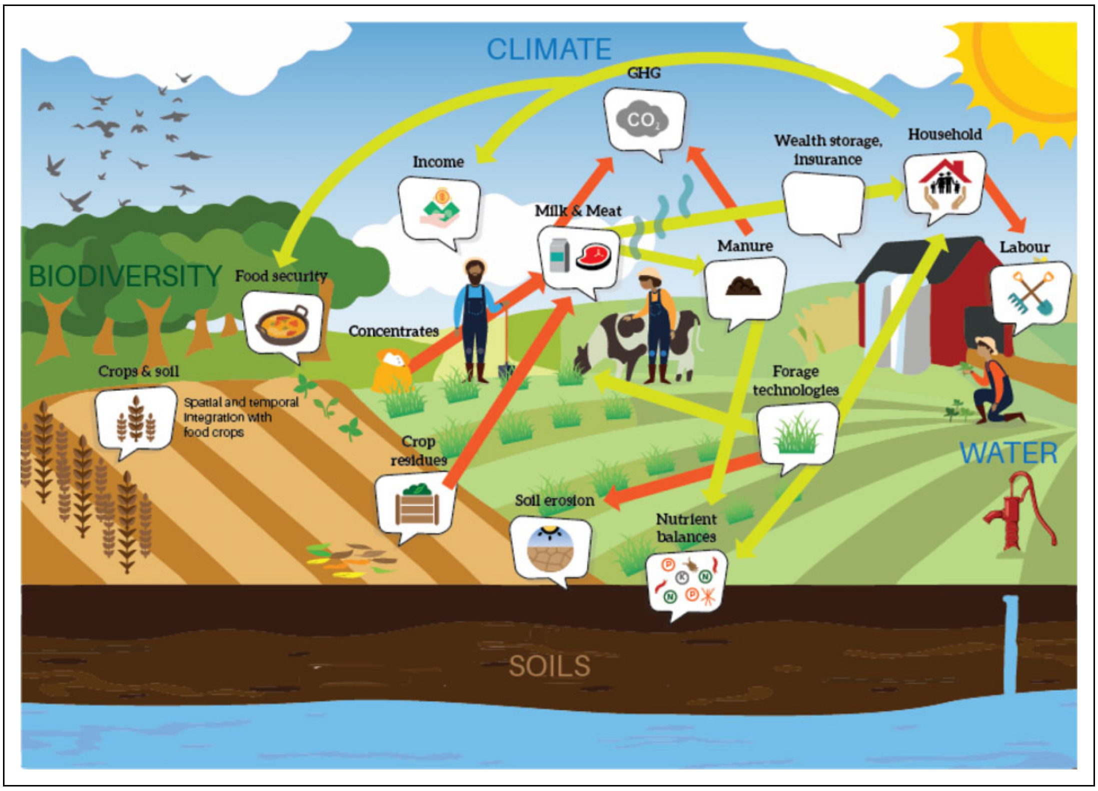

Figure 3. The role of improved forage technologies in mixed crop-livestock farming systems and their potential impacts on productivity, environment, and livelihood dimensions. The farming system is subdivided into crops and soil, livestock and manure, and household components.

into farming systems depended on many factors, including soil fertility, land tenure, safety, and predominant livestock management system (Paul et al., 2016). The push–pull system integrates forage grasses and legumes with maize, sorghum, or millet to decrease *Striga* and stemborer infestation, thereby increasing cereal yields. Napier grass, or *Brachiaria* hybrid cv. Mulato II in drier areas, is planted around the cereal crop to attract and trap stemborer moths. Silverleaf desmodium, and greenleaf desmodium in drier areas, is intercropped with the cereal and causes abortive germination of *Striga* due to root exudates (Khan et al., 2014). The smart use of agro-biodiversity in the push–pull system is providing spatial niches for forage crops that have shown to benefit farmers (Chepchirchir et al., 2018).

However, more systems agronomy is needed to produce robust socio-ecological niches for various systems that can be scaled. Agronomy research, in general, has been criticized for lacking "scalability" by emphasizing local relevance of research results. Researcher-controlled trials are well suited to identify single yield-influencing factors and to elucidate underlying mechanisms. However, they fail to predict realistic performance under farmers' conditions, as yields are determined by the interplay of several factors within environment, genotype, and management domains. Only a small proportion of farmers will reach the average yield under experimentation, owing to the large variability of agroecological conditions and management that affect performance. Statistical methods continue evolving to consider and embrace this variability (Vanlauwe et al., 2016). Moreover, participatory farmer-led on-farm trials can support experiential learning by farmers to adapt and fit new technologies into their own systems (Paul et al., 2014). Variability in forage agronomy data from SSA is often high. This can partly be explained by the adaptation of forages to a wide range of agroecological conditions and yield variation depending on cultivar and its interactions with cutting regime and fertilization. However, there is also a lack of applying standardized methods in forage agronomy data collection and analysis, which reduces comparability across sites. Forage agronomy has been less resourced than that of other field crops, resulting in fewer publications and less established evaluation methods. Multi-locational, consistent, high quality, and inter-operational data are crucial for forage agronomy to keep pace with the challenge of scalability and the evolution of (big) data science, geospatial analytics, and decision support tools to produce context-specific advice.

Systems modeling for reducing agro-environmental trade-offs

Improved forages are thus at a unique position of mixed farming systems, directly linking crop, livestock, and soil components. Changes in livestock feeding can have multiple impacts on productivity, environmental, and livelihood dimensions across various crop-livestock systems (Figure 3).

Farming systems approaches and modeling can be used to explore forage integration and relationships with various other components of farming systems and estimate their multidimensional impacts and trade-offs. Models are useful to study and predict the behavior and performance of agro-ecosystems. They can also reduce resource requirements from field and farm experimental research, and they can help to formulate management recommendations (Jones et al., 2017). Agricultural systems modeling has been applied to questions of system intensification and diversification beyond single crops and minimizing trade-offs and exploiting synergies between system components (Groot et al., 2017). Trade-offs influence the adoptability, impact, and sustainability of possible innovations and future pathways. Trade-off analysis often employs interdisciplinary, bio-economic models to address those multiple dimensions in one approach. Multi-objective optimization, in particular, is considered a useful approach as farmers are not ultimate profit maximizers but have to balance various functions of their production system (Kanter et al., 2016; Klapwijk et al., 2014b; Salmon et al., 2018). Quantitative systems modeling can help to systematically explore trade-off frontiers, which can be expected to be different for farm types with contrasting biophysical conditions and resource endowment (Groot et al., 2012). Changes in available technologies, market conditions, and policies can lead to adjustment of the efficiency frontiers and can, thus, reduce the trade-offs between performance criteria such as profitability and GHG mitigation (Descheemaeker et al., 2016a). Ex ante impact assessment and prioritization studies are increasingly important to target scarce research and development resources and support decisions for improved adaptation and mitigation of mixed crop-livestock systems in SSA (Descheemaeker et al., 2016a; van Wijk et al., 2014).

To date, there are only a few recent studies that employ farming systems modeling tools to explore potential whole-farm multidimensional impacts of planted forages. Simulation results from Tanzania illustrated that households with improved cattle would be able to achieve a higher income and lower methane emission intensity with improving quality and quantity of their feed than households with local cattle (Shikuku et al., 2017). Multi-objective optimization of various smallholder livestock systems in Northern Tanzania revealed how reducing ruminant numbers, replacing local cattle with improved dairy breeds, and improving feeding through on-farm Napier grass cultivation were synergetic options, although systemic obstacles to adoption existed (Paul et al., 2020). The improved livestock feeding scenario in Rwanda increased food security at only a small GHG trade-off, although it was the least equitable strategy reaching more well-off farmers (Paul et al., 2018). Strikingly, integrated knowledge on the potential impacts and trade-offs of improved forages on productivity, environment, and livelihood dimensions across various crop-livestock systems in East Africa is still limited and fragmented and has not been consistently translated into decision advice.

Conclusions

In this perspective article, we have shown that improved forages in East Africa are at a crossroads: if adopted by farmers at scale, they can be a cornerstone of pathways toward intensified sustainable livestock systems in East Africa. Forages occupy a key role in smallholder farming systems, linking soil, crop, and livestock components. Changes in livestock feeding can have multidimensional impacts on farmers' livelihoods in terms of productivity and environmental quality. Systemic characteristics, including the need to change the entire production system and multidimensionality of livestock, affect adoption of improved forages and call for multidisciplinary thinking. Further, forage technologies need to be matched with agroecological and socioeconomic contexts to address competition for land and fulfill various production objectives. Robust, "scalable" systems agronomy is needed to develop context-specific advice and decision support on socio-ecological niches for forages. Farming systems modeling can be employed to estimate multidimensional impacts of forages and for reducing agro-environmental trade-offs. Translating modeling results into decision advice, without losing sight of farming systems intrinsic complexities, needs further development. Multidisciplinary farming systems approaches are pivotal to bring tropical forages into wider use and to support sustainable livestock development trajectories in East Africa.

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